Which Way Is the Flow?

David Kao
NASA Ames Research Center
T27A-2
Moffett Field, CA 94035

Introduction

The line integral convolution (LIC) technique has been known to be an effective tool for depicting flow patterns in a given vector field. There have been many extensions to make it run faster and reveal useful flow information such as velocity magnitude, motion, and direction. There are also extensions to unsteady flows and 3D vector fields. Surprisingly, none of these extensions automatically highlight flow features, which often represent the most important and interesting physical flow phenomena. In this sketch, a method for highlighting flow direction in LIC images is presented. The method gives an intuitive impression of flow direction in the given vector field and automatically reveals saddle points in the flow.

Directional LIC

A fast and simple method to depict overall flow direction in the given vector field is presented. The method, which is referred to as *directional LIC*, colors LIC flow texture based on its orientation and uses local streamlines computed in LIC to show the actual flow direction. A description of the method follows. For each pixel in the vector field, the orientation of the flow is classified as either clockwise or counterclockwise. The direction of orientation can be determined by the *curl* of the local velocity vector V, where $V=(u,v,w)$ and $curl\ V = [dw/dy-dv/dz \quad du/dz-dw/dx \quad dv/dx-du/dy]^T$, which represents the axis of rotation and the amount of rotation. For 2D vector fields, $curl\ V = [0 \quad 0 \quad dv/dx-du/dy]^T$ and represents a vector perpendicular to the XY plane. Diretional

LIC uses a color input noise, where the RGB values are convoluted individually; and the texture color at each pixel is set according to *curl V*. If *curl V* is positive (ie. the flow is rotating in counter-clockwise direction), then the blue component is set to zero, thus the texture would be colored in some variation of yellow hues. Otherwise, the red component is set to zero to create cyan flow textures when *curl V* is negative. This results in a color LIC image colored according to flow direction. However, it only shows regions with same flow direction, not the actual particle path in each region. A straightforward method is to release particles/dyes randomly in the input field and overlay the particle pathlines on the LIC image. Depending on the seed locations and the length of the pathlines, the underlying LIC flow texture may be obscured. A more ideal selection of seeding is where the flow is changing from one orientation to another, i.e., neighboring pixels have opposite signs of *curl V*. Pixels in these regions are in the ***transient zones***. Figure 1 compares directional LIC (1b) with traditional monochrome LIC (1a) with two data sets. A benefit of the direcitonal LIC method is that it automatically highlights saddles in the flow. It can also highlight flow separation and flow reattachment, since the flows are going in oppositive direction. The transient zones are the boundaries where the texture color changes from yellow to cyan. Since initially there could be a large number pathlines in the transient zones., to avoid cluttering, the number pathlines decreases over time. Furthermore, pathlines are terminated when they reach another transient zone. Figure 1c shows directional LIC with selective pathlines from transient zones.

Topology LIC

Another choice of seed locations for the directional flow lines are those near the critical points, i.e., points where the velocity is zero. Algorithms for computing critical points are well known in tensor field visualization. There are relatively few techniques that combine vector and tensor field techniques. We propose to further enhance feature LIC, by choosing seed points based on the critical point locations. This gives further insights about where the flow is changing and how it is changing.